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A SYSTEMS ENGINEERING APPROACH TO IMPROVING THE PEANUT GRADING SYSTEM

Floyd E. Dowell
USDA ARS
Nat. Peanut Research Lab
1011 Forrester Drive
Dawson, GA 31742

Richard P. Konstance
USDA ARS
Eastern Regional Res. Cntr.
600 East Mermaid Lane
Philadelphia, PA 19118

Charles R. Meyer
USDA ARS
Nat. Soil Erosion Lab
Purdue Univ.
W. Lafayette. IN 4790'

Abstract. Systems engineering was used to identify peanut grading system needs, establish requirements, and compare proposed solutions that meet consensus specifications established by all industry segments. Previous attempts to change the grading system were hindered by difficulty in getting all segments to agree on proposed changes. The systems engineering approach overcame this obstacle. Four conceptual designs that improve the current system are at various stages of development and implementation. These improvements are: high moisture foreign material identification; measuring moisture during sampling; measuring single kernel moisture; and grading larger samples with an automated sample cleaning, shelling, sizing, and data collection system. Each of these improvements help ensure consumer demands for quality are met while not unfairly burdening any one segment of the peanut industry.

INTRODUCTION

Domestic and foreign consumer demands for food quality intensify as consumers focus on potential perceived or real quality problems, and as they expect an increasingly wholesome and consistent food supply. Peanuts are no exception. Particularly, potential quality problems such as aflatoxin, foreign material, and off-flavor, threaten both export and domestic markets. Thus, quality measurement procedures must accurately reflect true quality of the lot marketed so subsequent processing and handling results in only high quality peanuts reaching consumers. Besides determining value, quality measurements give the seller information on the growing, harvesting, handling and storage practices that lead to a specific quality level. The seller may use this information to adjust any of these practices to improve peanut quality for marketing subsequent lots. Quality measurements give the buyer information so subsequent handling and processing results in peanut products that meet or exceed consumers' quality expectations.

The current grading system for farmer marketed or farmers' stock peanuts has remained essentially unchanged since the 1960's. Requests to improve the system have come from such peanut industry associations as: the National Peanut Council, which includes farmer, sheller, manufacturer, and regulatory representatives; the Federal-State Inspection Service (FSIS), which oversees peanut grading; the Peanut Grading Working Group, which includes representatives of all segments of the peanut industry and provides direction and critique of grading research; the Peanut Administrative Committee, which administers the marketing agreement for peanuts; and the Southeastern Peanut Association, which includes shellers in the southeastern US. Suggested improvements include: eliminate inspector subjectivity; reduce labor required; reduce inspection costs; provide foreign material piece count and identification by type; ensure sample accurately represents the load; provide a system of premiums or penalties based on grade factors to encourage proper practices such as growing, harvesting, storage, etc.; and measure levels of naturally occurring or applied chemicals. All these changes are requested by the peanut industry as part of their plan to address short and potential long term consumer concerns, while returning a fair profit to all segments of the peanut industry.

Description of the Current System. Farmers' stock and shelled stock peanuts are inspected under both federal and state supervision (USDA, 1990). Approximately 600,000 lots of peanuts are inspected each year at about 500 locations throughout the peanut belt which stretches from Arizona, to Florida, to Virginia. FSIS employs about 2000 temporary inspectors to grade these lots during the harvest season from August to November. Equipment used in the inspection process, and inspectors' salaries are provided by the person buying the peanuts. The grade quality factors are percentages of: foreign material (FM), debris such as sticks and rocks; loose shelled kernels (LSK), kernels shelled by harvesting and handling before marketing; moisture content (MC); sound mature kernels (SMK), undamaged edible kernels; sound splits (SS), edible kernels split in half during shelling; damaged kernels (DK), kernels discolored by freezing, insects, or molds like *A. flavus*; other kernels (OK), small inedible kernels; hulls; extra large kernels (ELK), found only in Virginia type peanuts; and fancy pods, large pods from Virginia peanuts only.

The farmers' stock grading process begins with sampling 5 to 20 random locations within a 5 to 20 ton lot using a pneumatic sampler, producing a 30 kg sample. This sample is riffle divided into two 1800 g samples. Riffle dividing repeatedly halves the sample until the 1800 g samples are obtained. One is graded and the other held as a check. FM and LSK are removed from the grade sample and percentage of each is determined by hand calculation. Penalties are assessed for FM more than 4%, and samples with more than 10.49% must be further cleaned before marketing. LSK receive oil stock price which is about 1/6 of edible stock price. Whole pods from the cleaned sample are reduced to a 500 gram sub-sample which is pre-sized to improve shelling efficiency. After shelling, the kernels are sized on a screen shaker and sampled for moisture content. Moisture above 10.49% requires the lot to be further dried and subsequently regraded.

In the sizer, the kernels are separated into three fractions: kernels which ride a 16/64 by 3/4 inch slotted screen (+16's); kernels which fall through the screen (-16's); and split kernels. The proportion of each category is hand calculated.. The -16's are not edible and receive the lower oil stock price. The +16's and the splits are visually inspected to determine the percent of discolored, or damaged, kernels. All kernels, including LSK, are examined for visible A. Flavus (VAF) which is an indirect indication of aflatoxin, a suspected carcinogen. Detection of A. Flavus on any kernel in the sample rejects the entire lot. The farmer has the option of accepting oil stock price for this lot or withholding it from market and using the peanuts for seed or other non-food purpose. Once grade, or percentage of edible and inedible material, is determined and the peanuts are purchased, the lot is placed into aerated storage and subsequently shelled and processed into edible products or crushed for oil, depending on grade. Lot value is calculated from the grade percentages using a price chart. SMK, SS, LSK, and OK add value to the lot; whereas excessive MC, SS, FM and DK result in penalties.

Problems with the Current System. Research and industry experience shows errors associated with the current peanut quality measurement system, as with any commodity grading system, are due to sampling, equipment, and human errors. Inaccuracies can cause over or under payment to the seller, improper segregation of the peanut lot, or inaccurate grade information supplied to the buyer. Dowell (1992), Dickens et al. (1984), Davidson et al. (1990), and Whitaker (1991) reported coefficient of variation (CV) values for all grade values. Some sampling error is caused by the abrasive action of the pneumatic sampler shelling pods during the sampling process (Dickens, 1964; Davidson et al., 1990). The kernels from the shelled pods are now classified as LSK and the hulls from the shelled pods classified as FM. Errors after sampling are from human and equipment errors. These include: sizing kernels, measuring moisture (Dowell and Lamb, 1991), determining damaged kernels (Dowell, 1990), measuring split kernel outturns (Davidson et al., 1990), and determining aflatoxin.

The current farmers' stock cleaner and sheller requires considerable additional hand cleaning and shelling from the inspector. The feeding mechanism of the cleaner loses some dirt during the cleaning process, biasing the sample. Small pods fall through the sheller grate, requiring hand shelling of these small pods. Consequently some inspectors, especially when under time pressure, may select only large pods to be shelled. This reduces hand shelling and sample processing time but biases the sample. Screens for the kernel sizer can be out of tolerance and shakers improperly set, causing inaccurate large and small kernels counts.

The current system requires inspectors hand record and calculate grade factors. The allowable tolerance, or amount of sample that can be lost, for sample accountability is 5g, based on a 500 g sample size. If this tolerance is not satisfied when adding all fractions of the graded sample, regrading is required. Due to time constraints, some inspectors may use a slightly larger sample size to ensure the tolerance is met if some of the sample is lost, however, this results is an overestimation of some grade factors.

Inability of the current grading system to accurately detect aflatoxin has been targeted by several industry segments and documented by several researchers (Dowell et al., 1992; Tsai et al., 1989; Davidson et al., 1984; Dickens and Welty, 1969; Dickens and Satterwhite, 1971; National Peanut Council, 1989). These researchers showed the current visual A. Flavus method is subjective and less accurate than chemical testing. They showed 2 to 30% of tested lots were incorrectly accepted while containing aflatoxin, and 1 to 30% of tested lots were incorrectly rejected. A more accurate test for aflatoxin than the VAF method is needed.

Although the technology exists to improve the grading system, any proposed changes must meet specific industry requirements including: cost, time, labor, and accuracy. Perhaps the biggest obstacle to implementing any proposed change is the need for approval from all segments of the industry, from farmers to manufacturers. Any segment can veto a change if it might adversely affect them. For this reason, a systems engineering approach was used to determine exactly what each industry segment expected from the grading system and what they were willing to pay or sacrifice for grading system changes. Many past efforts to change the grading system have failed primarily because at least one industry segment did not have adequate input into the proposed change and felt they would shoulder a disproportionate cost for benefits received. This paper reports solutions which can be incorporated to improve the peanut grading system which adhere to the requirements established by all industry segments using the systems engineering approach.

GRADING SYSTEM REQUIREMENTS

Determining exactly what each industry segment expects from the peanut grading system has been one of the more difficult parts of this research. In general, industry members agree that grading must accurately measure quality with minimal cost and within the time constraints dictated by marketing conditions. Considerable time was spent interviewing representatives of all industry segments to precisely define terms like "accurately" and "minimal", and reduce needs to specific measurable and mutually agreeable requirements. The performance (PERF), utilization of resource (U/R), and trade-off (T/O) requirements developed to precisely quantify these terms are presented below.

Performance Requirements. The proposed system should be no less accurate than the existing system. Coefficient of Variation (CV) (Steele and Torrie, 1980) will be used to compare accuracy. CV is the sample standard deviation divided by its mean. More variation between samples from the same lot produce a higher CV; smaller sampling, human, and equipment errors produce a smaller CV. For a proposed solution to be acceptable, the CV should not increase for any single grade factor or price/ton. Dowell (1992), Dickens et al. (1984), Davidson et al. (1990), and Whitaker (1991) all reported CV's of about 20, 20, 2, 2, 25, 13, 43 and 2 % for FM, LSK, SMK+SS, SMK, SS, OK, DK, and $/ton, respectively.

The complete sample processing time of the proposed system should be no slower than the present system. From cleaning to final certificate generation, the present system processes a sample in about 20 minutes. However, when samples are staged throughout the grading system, a sample is completed about every 6 minutes (National Peanut Council, 1990). The improved system must complete a sample every 6 minutes or less to prevent slowing down the harvesting and marketing process.

The system must not decrease inspector safety. Levels of 0.5 micron dust particles in grading rooms can not exceed 90,000 particles per minute (Dowell, 1989). About 41 grading related injuries occur per year with the present system, with an average claim of about $1114. An acceptable new system must have dust levels and injury costs below these levels.

Utilization of Resources Requirements. Resources required, such as money and personnel, should not increase. Current equipment costs are: pneumatic sampler - $30,000; sample divider - $2000; sample cleaner - $1500; pod presizer - $1250; sample sheller - $1900; kernel sizer - $700; kernel splitter - $2250; moisture meter - $3150; scale - $1200; and microscope - $525. Equipment for a new system should cost no more than the equipment it replaces.

The proposed system should not require more maintenance than the present system. Maintenance of the present equipment costs about $1000/year and requires about 20 hours of service per year.

Depending on the state, the labor cost for inspection is $4 to $5 per sample. The improved system should not require a higher labor cost than the present system, or more labor, or more highly skilled labor. Currently there are about 500 buying points employing about 2000 inspectors. Any proposed system improvement should reduce the total number of inspectors. Minimum education for inspectors is a high school degree.

The proposed system should reduce the number of procedures prone to inspector error. Presently inspectors hand record 24 numbers and hand calculate 14 percentages per sample. Previous research (National Peanut Council, 1988) showed that 10% to 25% of all grade certificates (FV-95's) have illegible data, calculation errors, or missing data, and 2% to 17% of these cause a change in dollar value of the load.

The proposed system should not reduce the edible supply of peanuts through factors like segregating too many lots, which removes peanuts from the edible market. The percentage of each year's crop determined unfit for edible products (SEG III) varied from 0.5% in 1982 to 9.12% in 1990 due to environmental conditions.

Tradeoff Requirements. Tradeoff requirements objectively define how PERF requirements of competing concepts will be traded off against U/R requirements, if one system scores better in PERF and the other scores better in U/R. In the peanut grading system some of the PERF requirements are mandatory; however, all of the U/R requirements can be traded off against each other. For example no proposed system which decreases inspector safety will be accepted, regardless of the benefits. However, equipment costs, or other costs or resources, can increase provided this increase is offset by something else like a decrease in maintenance cost or an increase in value added to the peanuts. The following tradeoff formula was used: Overall score = ((PERF score + U/R score) + 2(PERF score x U/R score))/4. This formula penalizes proposed solutions scoring exceptionally well in one area but scoring poorly in others. A score of one reflects an ideal system. Any real system will score between 0 and 1.

Figures of Merit and Scoring Functions. The figures of merit (FOM) for each performance or U/R requirement were prioritized by the peanut industry resulting in the weights shown in Table 1. A score for a FOM is a measure of how well each proposed solution performs for that FOM and is calculated from a scoring function. A score of 0 means a proposed solution contributed nothing to that FOM, whereas a score of 1 means the proposed solution did everything expected for that FOM. The scoring function describes how the score changes for a given change in the FOM. This method of evaluation allows objective comparison of different proposed solutions and an overall score to be computed. For example, the current grading system SMK CV is 1.82% and, since the current system is the benchmark, it receives a score of 0.5. If a proposed system doubles sample size, research shows the CV reduces to 1.48%. Assuming a linear relationship and a score of 1 when CV is 0, the proposed system CV yields a score of 0.59. This score is weighted with the second level weight of 0.20 at item 1.1 in Table 1 and combined with other FOM scores at other levels. Other scoring functions, such as sine functions or normal distributions, can be used, but a straight line relationship was assumed in most of this work.

System Test Requirements. USDA statisticians were consulted when developing the system test plan. Three prototypes will be tested at the National Peanut Research Lab (NPRL) for one harvest season. Fifty samples in the low, medium, and high ranges of each quality factor affected by the proposed change will be tested. FSIS licensed inspectors will conduct all tests. Additional years testing may be required if the variation between crop years is determined to be greater than variations found within crop years. However, if regional weather patterns provide large variations in crop quality, one years' data will suffice. Proposed changes may be approved for each peanut type separately. Accuracy tests will be conducted by collecting multiple samples from one lot for CV measurements. The remaining tests will be conducted by obtaining samples from multiple lots. In both cases, samples will be divided into four subsamples, one subsample will be graded using the existing system and the remaining 3 subsamples graded on each of the three prototypes.

PROPOSED SOLUTIONS

The PERF and U/R requirements established in the previous section allow comparison of any proposed improvements to the grading system. Brief descriptions of some potential solutions follow. Table 2 lists the PERF, U/R, and T/O FOM scores for each conceptual design. Scores for each component and level are not given, but general comments on strengths and weakness are made.

Existing System. One solution is to not change anything, but use the existing grading system. The T/O score (0.3354) of this system serves as a benchmark that any proposed solution must exceed. The previous discussions describe the weaknesses of the existing system such as the inherent subjectivity, excessive labor requirements, and sampling errors. The existing system strengths include its use of relatively unskilled workers, and low technology and low cost equipment.

Improved Sampling Methods. The present pneumatic sampling procedure creates FM and LSK and does not obtain FM larger than 3 in. diameter. Spout, instead of pneumatic, sampling removes peanuts and FM from material flowing past the sampler and collects more of this large FM but requires the load be conveyed to a holding bin or to another trailer. Other advantages, such as cleaning the lot during transfer, can be incorporated into the spout sampling procedure. Davidson et al. (1990) showed spout sampling increases the sampling CV by about 5% for some grade factors, thus the Performance FOM scores decrease in comparison to the present system (Table 2) and do not compensate for the improved identification of FM. FM and LSK percentages are closer to shelling plant outturns, but not necessarily better correlated.

Damage Detection. Present damage detection procedures require inspectors to visibly examine kernels for damage. The proposed solution incorporates sensors into the inspection process. This reduces inspector subjectivity but increases costs. Current technology does not provide an economically viable solution at this time.

Aflatoxin Testing. The current system identifies only A. flavus infected kernels. A conceptual design is chemically testing all samples to remove inspector bias and eliminate subjective indirect testing. However, skilled labor required, health risks, and equipment costs all increase, but aflatoxin levels in edible peanuts should decrease. Despite advantages of chemical testing, benefits do not outweigh costs. FDA lowering of allowable aflatoxin levels may dictate future implementation of this solution.

Foreign Material Identification. The current system weighs the total FM present and ranks the two most prevalent types of FM. A proposed conceptual design identifies particularly troublesome FM, such as high moisture FM, and reports the respective amounts. Identifying troublesome FM should reduce aflatoxin formation in storage by improving aeration and reducing high moisture concentrations but will increase cleaning costs in order to remove this identified FM. The PERF U/R and T/O FOM increase slightly for this potential improvement (Table 2).

Moisture Probe. Currently, about 10% of all grade samples are rejected for sale because of excess moisture. The proposed solution measures moisture content as the load is probed, measuring moisture without cleaning and shelling the sample. This causes only lots with acceptable moisture to be graded and results in more marketable trailers graded per day. Table 2 shows PERF benefits outweigh the cost increase of this probe.

Single Kernel Moisture. This conceptual design measures individual kernel moistures in addition to average moistures. Loads with excessive single kernel moistures are identified and dried further to reduce aflatoxin problems in storage. The additional quality information gained offsets the equipment costs.

Increase Sample Size; Automated Cleaning, Shelling, and Sizing; and Automated Data Collection. Some conceptual designs dictate additional improvements. For example, increasing sample size requires higher-capacity equipment to handle larger samples without slowing down grading. The percentage calculations are currently based on 500g of cleaned pods and calculations can be done quickly in the inspectors' head. A larger sample dictates automated data collection and calculations. This conceptual design processes a 1800 g sample from cleaning through sizing in one step. All pods from the 1800 g sample are shelled resulting in a pod sample size increase of about 300 percent. The larger pod sample size reduces sampling error, which is the largest component of total grading error (Dowell, 1992). However, more peanuts are destroyed by grading a larger sample. The cleaning mechanism of the conceptual design is more efficient than the present cleaner, reducing hand cleaning. Small unshelled pods are recirculated through different sheller stages until all pods are shelled, reducing hand shelling. The sizing mechanism reduces variation in measuring kernel size. All data is collected on a computer interfaced to the scales and the respective calculations are made. Equipment and sample costs increase with this conceptual design, but errors and labor requirements decrease and offset any cost increase.

Combined System. Four proposed solutions resulted in scores exceeding the present system. These four solutions are: foreign material identification; moisture probe; single kernel moisture; and automated cleaning shelling, sizing, data collection and increased sample size. If these solutions are implemented together, the resulting scores offer the highest PERF and T/O scores of any proposed solution.

IMPLEMENTATION, SUPPORT, AND FUTURE CHANGES

The evaluation of the proposed solutions served to focus peanut grading research towards those areas scoring higher than the current system. Following is a summary of progress towards incorporating the four highest scoring conceptual designs.

Implementation. Those conceptual designs with T/O scores greater than the existing system are at various stages of development and implementation. High moisture FM identification was implemented during the 1992 harvest season. Several moisture probes are being investigated and field testing is planned for the 1993 harvest season. The single kernel moisture meter has been field tested for several years and final changes are being made on the commercial prototype. Changes in the Marketing Agreement for peanuts are being considered by the Peanut Administrative Committee to require single kernel moistures be measure on all lots.

A commercial prototype of the automated data collection system was developed through a cooperative research and development agreement and the system has been approved by FSIS. This system is currently marketed by an equipment manufacturer. A laboratory prototype of the automated sample cleaning, shelling, and sizing system was developed and tested using samples from the 1992 harvest season. A commercial prototype of this automated system is being developed by an equipment manufacturer through a cooperative research and development agreement. Field testing of the commercial prototype is planned for the 1993 harvest season.

Support. The automated data collection system will be supported and serviced by the equipment manufacturer. All other equipment will be supported and serviced by FSIS as part of their maintenance network currently in place for their existing equipment.

Modifications, Retirement, and Replacement. Consumer and industry demands continual;y ch nge as preferences change and crises arise, thus on-going changes to any proposed system will be requested. Currently, requests for grading system changes requiring research are conveyed to the Agricultural Research Service (ARS) through regular meetings of the Peanut Grading Working Group, or through appropriate administrative personnel. ARS will continue to respond to needs to modify, retire, or replace the improved system as they arise. The principles outlined in this paper will be used to identify, prioritize, and address any requests.

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Table 1. Weights for performance and utilization of resources figures of merit. Weights for each category in a given level add to 1.0.

	Weights at Each Level			
	1st	2nd	3rd	4th
Overall Perf. Figure of Merit				
1. Provide Accurate Grade Information	0.40			
1.1 SMK Accuracy		0.20		
1.2 AT; DK Accuracy		0.15 ea[1]		
1.2.1 DK weight by Type			0.10	
1.2.1.1 freeze; fungal DK				0.30 ea
1.2.1.2 insect, curing, concealed, other				0.10 ea
1.2.2 Detect Presence of DK			0.30	
1.2.2.1 freeze; fungal DK				0.30 ea
1.2.2.2 insect, curing, concealed, other				0.10 ea
1.2.3 Total DK Weight			0.60	
1.3 FM Accuracy		0.10		
1.3.1 FM Piece Count			0.40	
1.3.1.1 nut grass; johnson grass				0.40 ea
1.3.1.2 sticks; rocks; gherkins; glass; dirt; corn; etc.				0.01 ea
1.3.2 FM Weight by Type			0.10	
1.3.2.1 dirt				0.80
1.3.2.2 sticks; rocks; gherkins; glass; dirt; corn; etc.				0.01 ea
1.3.3 FM Total Weight			0.20	
1.3.4 Detect Presence of FM			0.30	
1.3.4.1 high moisture FM (4 types); metal; glass; lg. rocks				0.10 ea
1.3.4.2 nutgrass; johnson grass; corn; wood				0.05 ea
1.3.4.3 sticks; rocks; dirt; etc.				0.01 ea
1.4 LSK; MC Accuracy		0.10 ea		
1.4.1 MC Average			0.60	
1.4.2 MC Range			0.30	
1.4.3 MC Zone			0.10	
1.5 SS; Pesticide Residue		0.05 ea		
1.5.1 Lasso			0.35	
1.5.2 Temik			0.25	
1.5.3 Kylar; Total Use by Type			0.15 ea	
1.5.4 Other			0.10	
1.6 OK; Hulls; ELK; Fancy; Peanut Type		0.02 ea		
2. Farmers' Stock Price Accuracy	0.20			
3. Return Trailers Quickly; Safety	0.15 ea			
3.1 Dust, injuries		0.40 ea		
3.2 # Missed Days, # Appointments		0.10 ea		
4. Reliable, Dependable Eq.	0.10			
4.1 Availability		0.40		
4.2 Reliability		0.30		
4.2.1 Avg. Time Down			0.40	
4.2.2 # Times System Down; Main. Time			0.30 ea	
4.3 Maintainability		0.30		

Table 1 (Continued). Weights for performance and utilization of resources figures of merit. Weights for each category in a given level add to 1.0.

	Weights at Each Level			
	1st	2nd	3rd	4th
Overall U/R Figure of Merit				
1. Increase Profits	0.60			
1.1 Farmer's Profits; System Profits		0.50 ea		
2. Maintain or Reduce Costs	0.10			
2.1 Inspection Eq. Costs		0.40		
2.2 Equipment Maint. Costs; Op. Costs		0.30 ea		
3. User Friendliness	0.10			
3.1 Train Time; # Regrades; Corr. Time; Entry; # Personnel		0.20 ea		
4. Maintain Peanut Supply; Labor Pool	0.10 ea			
4.1 Average Time Positions Vacant		0.40		
4.2 # of Vacancies; Man-hours spent		0.30 ea		

[1]The weights are for each figure of merit listed.

Table 2. Trade-Off (T/O), Performance (PERF), and Utilization of Resources (U/R) figures of merit (FOM) scores for various proposed peanut grading system conceptual designs (ordered by T/O score).

Conceptual Design	PERF Score	U/R Score	T/O Score
1. Spout Sampling	0.407616	0.50	0.328808
2. Objective Damage Detection	0.4208	0.4971032	0.33406631
3. Measure Aflatoxin	0.4499	0.4690084	0.33523054
4. Current System	**0.4208**	**0.50**	**0.3354**
5. Foreign Material ID	0.425	0.50003639	0.33751683
6. Moisture Probe	0.4283	0.49843479	0.33842351
7. Single Kernel Moisture	0.4288	0.49905228	0.33895988
8. Automated Cleaning, Shelling, Sizing; Automated Data Collection; and Increase Sample Size	0.477432	0.502504	0.36493974
9. Designs 5-8 Combined	0.497132	0.50002746	0.37357969

BIOGRAPHIES

Floyd E. Dowell. Lead scientist, Agricultural Engineer, responsible for automating the peanut grading system since 1988. He received a B.S. and M.S. from Oklahoma State University and Ph.D. from the University of Illinois.

Richard P. Konstance. Lead scientist, Chemical Engineer, with 20 years of Food Processing Engineering experience. He received a B.S. from Drexel University and an M.S. from Pennsylvania State University.

Charles R. Meyer. Computer specialist, works with EXTRA and TESTOP models, and leads a 5-agency team to optimize and reprogram the WEPP soil erosion model. He received a B.S. and M.S. from Delta State University.